Polymer Bulletin
https://doi.org/10.1007/s00289-023-04770-0

ORIGINAL PAPER

Influence of plasma treatment on moisture management properties of cotton/polyester knitted fabrics

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Received: 27 December 2022 / Revised: 14 March 2023 / Accepted: 17 March 2023

Abstract
In this research, the effect of air plasma treatment on moisture management properties of cotton and polyester fibers blended in 0:100, 50:50, 100:0 ratios in four different structures: single jersey, cross-tuck, cross-miss and twill at two different loop lengths 0.29 cm and 0.32 cm is analyzed. It is clearly shown that the knit fabric made of 100% polyester has providing good moisture management properties. The moisture management properties mainly depend on the loop length and fabric structure of the fabric. The fabric made with 100% polyester of cross-miss knit fabric with a loop length of 0.32 cm has good moisture management property. The plasma treatment also has a significant impact on improving the moisture management properties of the fabric.

Keywords Knitted fabrics · Moisture management · Overall moisture management capacity · Plasma treatment · Polyester

Introduction

The human body should maintain and control the temperature of 37 °C and it is in regular contact with the surrounding environment. The sweating process is one of the important parameters which will impact on the thermal regulation of the human body. But this sweating process creates un-comfort to the human being [1, 2].

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Published online: 29 March 2023

The thermal comfort level of clothing fabric is evaluated by the properties moisture management behavior [3]. Hence, the moisture management properties of the fabric are essential for the comfort of the human being, especially on the protective clothing and sportswear in which more physical activities are required [4, 5]. Hydrophobic fibers are capable of dispersing the moisture quickly and initiate the process of drying. However, it will not prevent the wetness of the fabric. But, the fibers having high hygroscopicity will have low drying efficiency. So, a fabric with a two-layer structure which is developed by the various layers having different characteristics should have better temperature regulation than one formed from a single layer structure.

Geralde et al. [6] and Zhu et al. [7] have studied the two-layer fabric made with knitted and woven fabric used as a hygroscopic fabric without any further treatment. Mbise et al. [8] have determined that the hydrostatic pressure difference between the two layers of spacer fabric is the main parameter affecting the process of wicking.

During the activity of the human being like sports, work and exercise rapid sweat is released from the body of human being and the system of cooling reduce the additional heat developed by the body. As the sweat developed from the fabric or skin surface, the water vapor carries the additional heat [9].

The transfer of sweat from the surface of the skin by wearer fabric is significantly impacted by physical activity of the wearer and the moisture management property of the fabric. So, the comfort of the wearer is mainly depend on the moisture management property of the fabric. The characteristics of moisture management and testing method were investigated by many researchers [10–12]. Hu et al. [9] have developed the moisture management tester commercially used in recent years, it determines the measure of multidimensional liquid moisture transportation of woven and knitted fabrics. They also proved that polyamide fiber has a great potential to transport the sweat quickly from the human body and has the better overall moisture management properties. However, the overall moisture management performance of cellulose fibre is found to be poor when compared to polyamide fibres.

Süpüren et al. [13] have analyzed the moisture management behavior of various fabrics which is manufactured from polypropylene and cotton fibers and found that it has better moisture management properties when polypropylene fibres were utilized as an inner layer and cotton fibres has been utilized as an outer layer of the fabric. Wardiningsih and Troynikov [14] have examined the water transport behaviour of knitted fabrics which have been manufactured from recycled bamboo fibres with various cover factors and found that the moisture management properties of the fabric decreased with the increasing in the cover factor of the fabric.

Namlıgöz et al. [15] found that the transportation of liquid from cellulose/polyester blends was better than cotton/polyester blends. Troynikov and Wardiningsh [16] have experimented the behavior of moisture absorption of two-layer knitted fabrics of polyester/wool and bamboo/wool blends and it is stated that the bamboo/wool blended fabrics have higher overall hygroscopicity property than polyester/wool blended fabrics. Moisture management is the basic need for textile materials to exhibit the comfort level of the fabric. The method of mixing, the properties of the fiber components, and the proportions of the various fiber types affect the moisture-related capacity of the fiber material [17, 18].

Kan and Yuen have been experimented the plasma treatment as the mechanical and chemical method that is used for the modification of surfaces, as the fabric surface is influenced both chemically and physically without changing the bulk properties of the fabric [19]. Leroux et al. have found that the treatment of air and atmospheric plasma on the polyester fabrics have made a significant enhancement in the surface energy, water wettability and the water capillarity due to the production of carboxyl and hydroxyl groups [20]. Seki et al. has analysed that the oxygen plasma has enhanced the flexural and tensile strength of jute/polyester composites when it is treated with both the low and radio frequency of plasma system [21]. Hence, the aim of this research is focused on the effect of plasma treatment on the moisture management properties of the cotton/polyester blended knitted fabrics.

Materials and methodology

In this research, the cotton fibre of 36Ne and polyester fiber of 150 denier in the blend ratio of 0:100, 50:50, and 100:0 with different structures of cross tuck, single jersey, twill and cross miss. The fabrics were knitted with Mayer & Cie, 2016 model with two different stitch lengths 0.29 cm and 0.32 cm.

Geometrical properties

The geometrical parameters like thickness, stitch length and areal density of the knitted fabrics were estimated. The course and wale per unit length were determined by the standard of ASTM D3887. The thickness of the fabric was evaluated by using the Shirley thickness gauge as per ASTM D1777-96. The areal density of the fabric was determined using the standard of ASTM D3776. For each sample, a total of ten readings were recorded.

Plasma treatment

The knitted fabrics were treated with a Diener vacuum plasma device. The fabric samples were positioned between the plasma device's two electrodes. The working pressure can be changed by using the vacuum pump. After the evacuation process had been completed for 10 min, the electricity was turned back on. Up until the start of the glow discharge, the plate current was gradually increased. The electrical power between the electrodes was altered using the power control knob. All plasma treatments have been performed using a constant glow discharge plasma system powered by air gas and operating in an atmospheric environment. The plasma therapy lasted a consistent 10 min. The fabric sample was positioned between the electrodes, 7 cm separating it from each electrode. The machine was run at a frequency of 70 kHz.

Measurement of moisture management properties

The moisture management properties were measured using the SDL Atlas Moisture Management Tester as per the AATCC 195–2009. The equipment is worked based on the electrical resistance of the fabric when it is contact with the content of the water. There are two sensors present on the moisture management tester on the upper and lower surface of the fabric. The electrical resistance is related to the water content and electrical conductivity of the liquid in the various areas of the fabric. The electrical resistance is measured by the amount of water in the liquid content on the surface of the fabric. The fabric samples were cut into the standard size of $8.0 \times 8.0 \pm 0.1\ cm^2$. The samples were washed and ironed to remove the excess wrinkles and water on the fabric samples. All the specimens were conditioned for 24 h before the testing. The simulating sweating solution which is made up of 22.5 g of NaCl, 0.25 g of $CaCl_2$, 1 g of urea and 1.5 g of lactic acid in 1 L of distilled water. And it was exposed on the top surface of the fabricas per ASTM F1868-17. When the liquid is exposed on the fabric, it transmitted in all the directions. The sensors present on the moisture management tester will determine the moisture management characteristics based on the transmission of liquid content on the surface of the fabric. For each sample, a total of ten readings were recorded.

Data analysis

The two-way analysis of variance (ANOVA) has been used to determine the significance of variations in moisture management properties of cotton/polyester blended fabric samples after plasma treatment. The differences were considered to be significant if the p-value was less than or equal to 0.05.

Results and discussions

Wetting time

Wetting time is defined as the estimated time in which the top and bottom fabric surfaces are wetted and the wetting time normally measured in seconds. The wetting time of top layer and bottom layer are mentioned as WTt and WTb. The droplets of simulated sweat solutions are initially contacted with the outer surface of the fabric [22]. The wetting time of top and bottom surface of the cotton fabric sample is indicated in Fig. 1. It is clearly evident that the wetting time of the lower layer of the fabric is greater than the wetting time of the top layer of the fabric. This is due to the simulation sweating initially wetting the top surface then gradually moving to the bottom surface of the fabric. The wetting time is low for the fabric which is made of 100% polyester fibre. This is because the fabric made with 100% polyester fiber can wick water very fast and transport to the other layer of the fabric. The transportation of water from the top surface to the bottom surface of the fabric is very fast in polyester fabric because of the hydrophobicity and moisture wicking capacity of the polyester fibre. Thus, the fabric made with the 100% polyester fiber moves water faster than other fabric samples. Also,

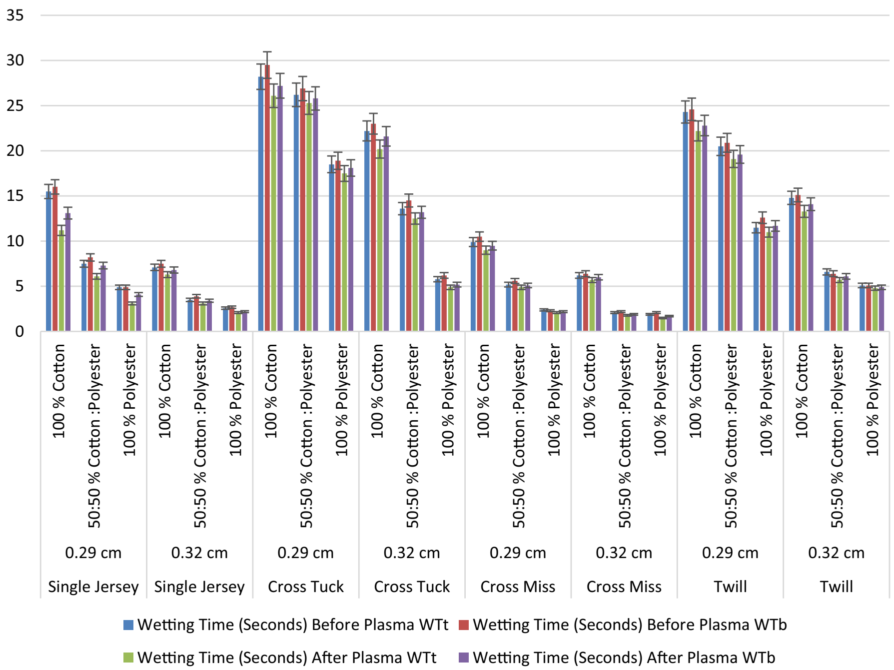

Fig. 1 Wetting time of bi-layer knitted fabrics

it is evident that the wetting time is lowest for the fabric with a loop length of 0.32 cm and this due to the lower fabric cover area and it has more space to pass the water. The results clearly indicates the wetting time is lowest for the cross miss structure. The wetting time is reduced after the air plasma treatment and it is due to the surficial etching of the fabric surface.

Absorption rates

Absorption rate mainly depends on the porous structure between the yarn and the fibre structures in the fabric. Figure 2 represents the absorption rate of the top and bottom surface of the fabric. The absorption rate increases with the increase in the content of the polyester fibre. The absorption of the top surface is less than the bottom surface of the fabric. The fabric made with cross miss structure and 0.32 cm loop length having maximum absorption rate. This is because the polyester fibre and cross miss structure of the fabric can suck and transport the water quickly. It is also noted that the absorption rate of the fabric is increased with the air plasma treatment.

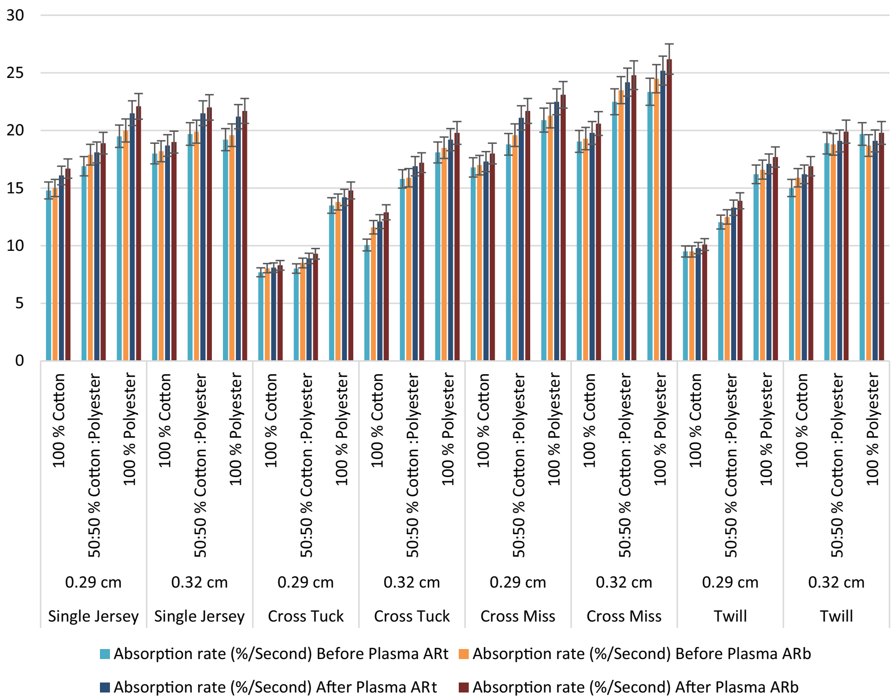

Fig. 2 Absorption rate of knitted fabrics

Maximum wetted radius

Maximum wetted radius is an important parameter in moisture management testing of textiles because it reflects the ability of a fabric to transport moisture away from the surface where it is generated. In other words, it measures the ability of a fabric to wick moisture away from the point of contact and distribute it over a larger surface area, which can help to enhance the evaporation of moisture and improve the comfort of the wearer. The maximum wetted radius of top and bottom surface of the fabric is shown in as shown in Fig. 3. The maximum wetted radius is increased with the content of the polyester fibre. This is because the capillary force characteristics of the polyester fibre that allows the liquid sweat to be quickly transmitted to the larger surface area of the fabric. Also, the polyester fabric has low hygroscopicity, good breathability and better water vapor permeability. The maximum wetted radius reduces with the increase in the content of the cotton fibres. This is because of the protruding fibres in the cotton fabric. The fabric structure also plays a major role in evaluating the transmission of moisture. The fabric which will wet in small areas and have a good drying behavior will give higher level of comfort to the wearer [23, 24].

The maximum wetted radius is obtained with the fabric having a cross miss structure. The wetted radius is increased with the loop length of 0.32 cm. This is

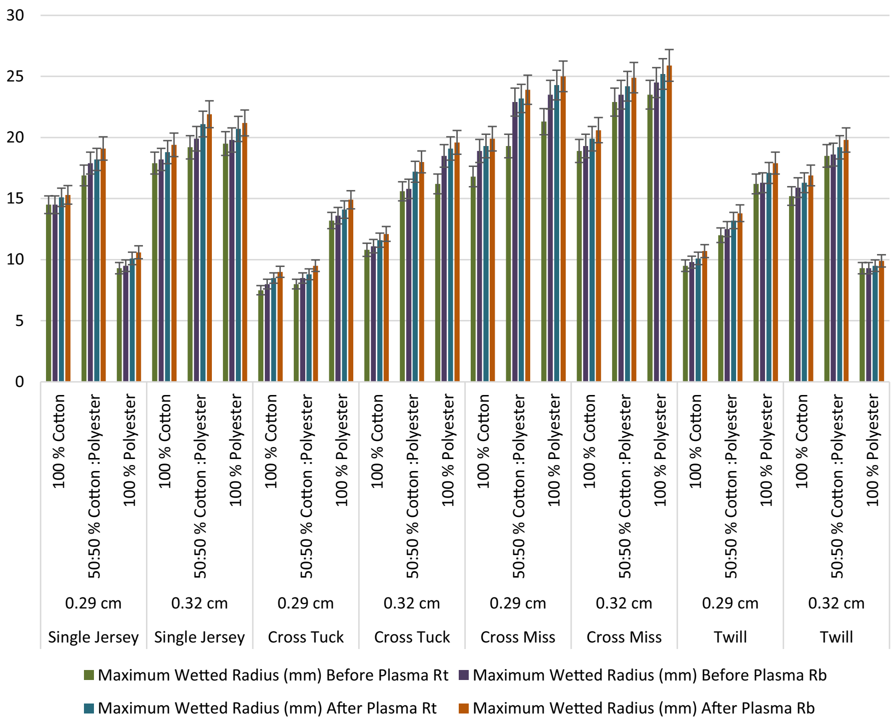

Fig. 3 Maximum wetted radius of knitted fabrics

because the longer the loop length, the looser the fabric structure. The maximum wetted radius is also increased with the air plasma treatment.

Spreading speed

The rate of spread is an essential factor in evaluating the drying capacity of the fabric and promotes the faster evaporation of the sweat which make the wearer feel more comfortable. The spreading speed of the top and bottom surface of the fabrics are shown in Fig. 4. The spreading speed of the fabric is increased with increasing content of polyester fibres. This is because the polyester fibres have a larger surface area which will help in faster evaporation of the liquid. The spreading speed is increased with the cross miss structure and for the loop length of 0.32 cm. Also, the spreading speed increases with the air plasma treatment.

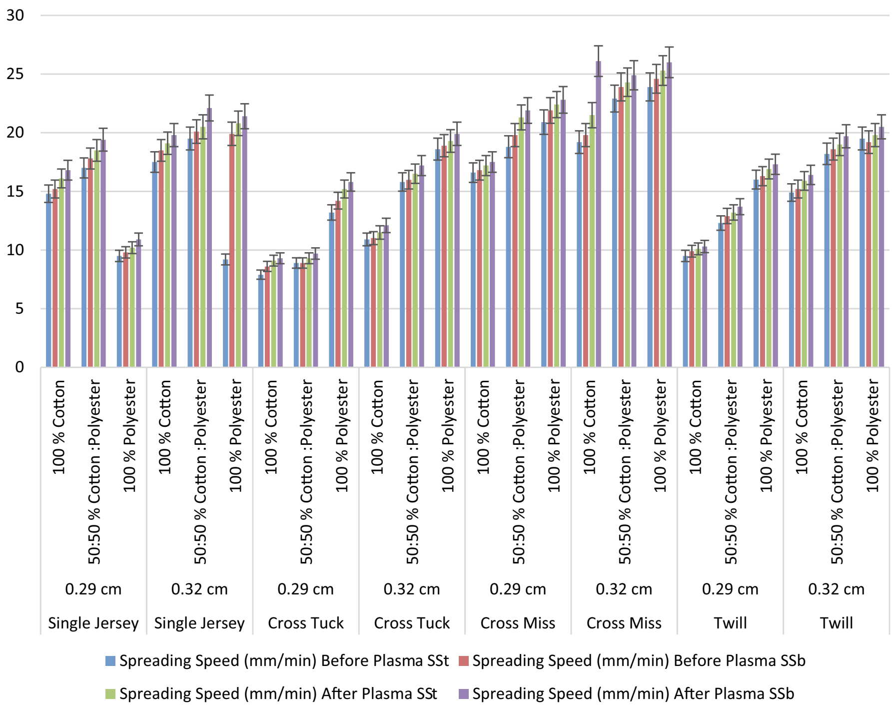

Fig. 4 Spreading speed of knitted fabrics

Accumulative one-way transport index

The accumulated one way transport index (AOTI) is a measure of the moisture transport properties of a fabric, which reflects the total amount of moisture that can be transported through the fabric over a given period of time. It is calculated by integrating the moisture transport rate over time and can provide valuable information about the overall moisture management performance of a textile. The Accumulative one way transport index of cotton/polyester blended fabrics is shown in Fig. 5. It is evident that the Accumulative one way transport index increases with the increase in the content of the polyester fibre. The fabric made with the cotton fibers shows a lower Accumulative one way transport index. This is because the fabrics absorbs and retains the sweat solutions in its fabric structure and provides the wearer with a wet feel. The Accumulative one way transport index value is increased with the cross miss structure and for the loop length of 0.32 cm. Also, the AOTI increases with the air plasma treatment.

Overall moisture management capacity

The overall moisture management capacity of a textile is a measure of its ability to absorb, transport, and release moisture. It reflects the combined effects of various parameters, including the wettability of the fabric, the rate and extent of moisture

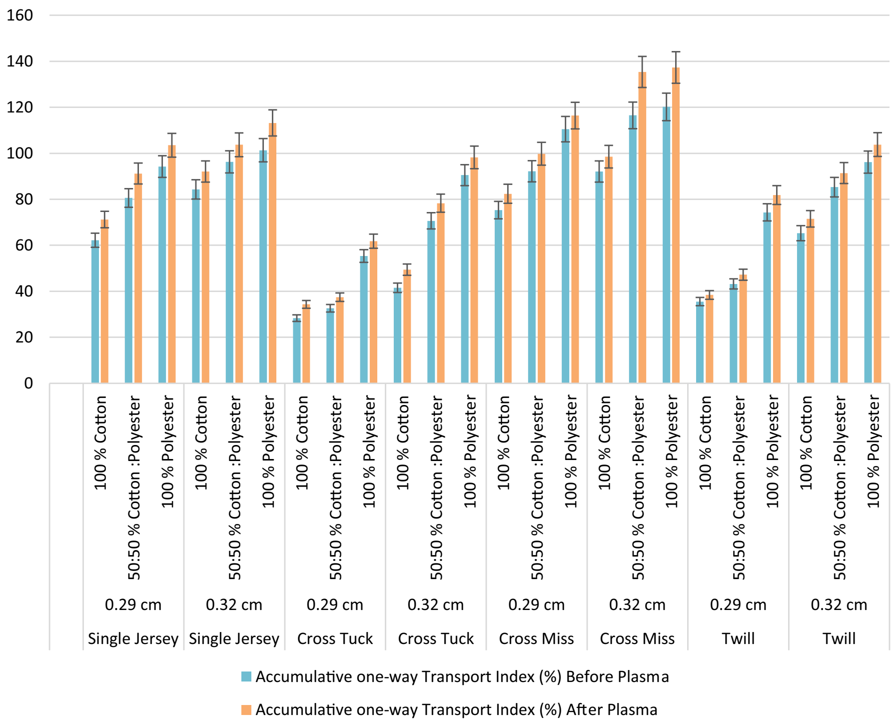

Fig. 5 Accumulative one way transport index of knitted fabrics

absorption, the speed and direction of moisture transport, and the rate and extent of moisture release. The overall moisture management capacity of the cotton/polyester blended fabrics is shown in Fig. 6. The fabric made with the polyester fibres has the highest overall moisture management capacity. This is due to the capillary behavior of the polyester fibre which transport the liquid quickly [25]. Hence the fabric made from the polyester fibers can easily pass the sweat and provides the wearer more comfort. The overall moisture management capacity decreased with the content of cotton fibres. This is due to the poor moisture control based on the high hygroscopicity and hydrophilicity. The overall moisture management capacity increased with the cross miss structure and for the loop length of 0.32 cm. Also, the spreading speed increases with the air plasma treatment.

Statistical data analysis

The statistical data of the study were evaluated using two-way analysis of variance (ANOVA) to determine the significance of plasma treatment on the overall moisture management capacity (OMMC) of cotton/polyester fabrics. The significance of the results was determined by analyzing the *p*-values. Table 1 presents the results of the

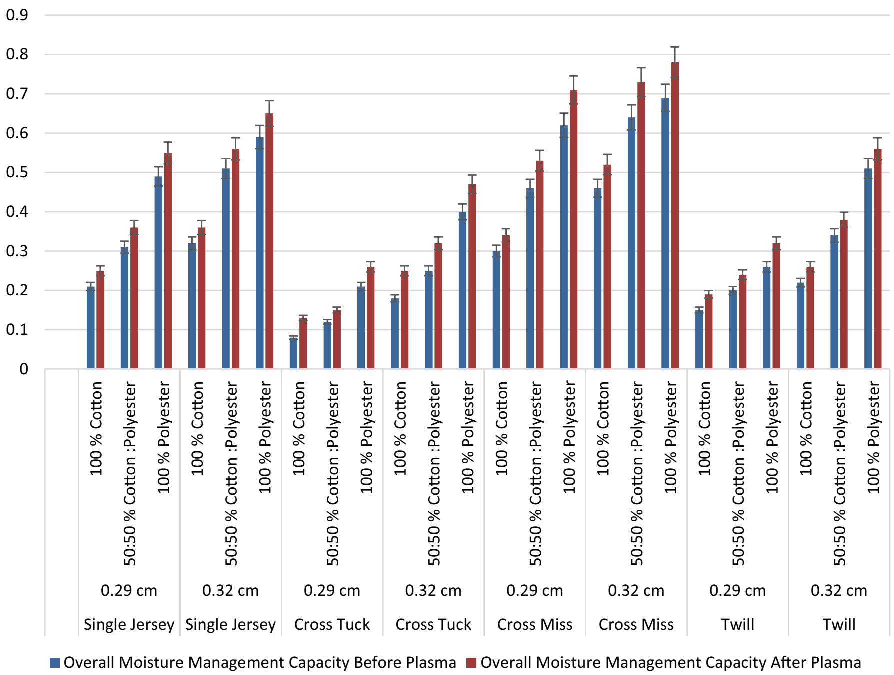

Fig. 6 Over all Moisture management capacity of knitted fabrics

Table 1 Two way ANOVA on cotton/polyester blended fabrics

Source of Variation	WTt	WTb	ARt	ARb	MWRt	SSt	AOTI	OMMC
Type of fabric	S	S	S	S	S	S	S	S
Loop length	S	S	S	S	S	S	S	S
Blend proportion	S	S	S	S	S	S	S	S

*S—Signifcant, NS—Non significant

two-way ANOVA, indicating that plasma treatment and the blending of cotton/polyester fabrics are significant factors for OMMC with p-values of less than 0.05.

Conclusion

The moisture management properties of the air plasma treated cotton/polyester blended fabrics have been studied. In accordance with the blend ratio the wetting time decreased with the increase in polyester fibre. Also, the wetting time is decreased with the cross miss structure and with the loop length of 0.32 cm. Also, the wetted radius, absorption rate, spreading speed, Accumulative one way transport index and overall moisture management capacity are increased with the content of polyester fibre, cross miss structure and with the loop length of 0.32 cm. Also the air plasma treatment has increased the overall moisture management properties of the cotton/polyester blended fabrics.

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